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ABSTRACT

A methodology for generating, describing, and organizing candidates for learning hierarchies is presented in this article for the purpose of facilitating attainment of desired outcomes in instructional design. Hierarchy entities are discussed in terms of information presented and performance required in instruction and items and skills underlying the performance. Performance requirements are described as items more important than elements of verbalizable knowledge. Skill substructures are seen as a separate conceptualization, and only the item features are considered in this paper in generating candidates. Components of description, comparison, and classification items include: elements, variable names, values, observation or measurement procedures, describers, correlational rules, and criteria for forming element subsets. Procedures for item generation are: (1) adoption of conventions for describing items in terms of tasks and content, (2) defining tasks, and (3) specification of content domains for tasks. The author points out that effects of hierarchies on knowledge transfer are determinable by analyzing items and skills of a task. A representation of learning hierarchies and tables of simple tasks are included. (CC)

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PROCEDURES FOR GENERATING CANDIDATES FOR LEARNING HIERARCHIES

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The goal of instructional design is the specification of sets of learning events which, if carried out, will reliably result in attainment of desired outcomes. An important contribution to this field is the notion of a learning hierarchy, a set of learning events sequenced to take maximum advantage of positive transfer effects (Gagné, 1962, 1968). This paper proposes a methodology contributing to a solution of the problem of generating candidates for such a hierarchy. Two questions are addressed as a basis for describing the proposed methodology:

1) What is the nature of the entities that make up a hierarchy?

2) What is the nature of the hierarchical relationship?

In answering the first question, a distinction is made between information presented as a part of instruction, and performance required as a part of instruction and/or assessment. A further distinction is made between an item and the skills which underlie the performance of that item and represent the basis for transfer. The second question is answered by defining a transfer relationship in terms of the above distinctions. Procedures for predicting transfer and evaluating proposed hierarchies are currently being developed and are not included in the present paper.

What is the Nature of the Entities in a Learning Hierarchy?

Learning Hierarchies vs. Information Hierarchies

In discussing this question Gagné (1968) makes a distinction between "verbalizable knowledge" and "intellectual skills or cognitive strategies." The same distinction is reflected in the contrast between "what the individual knows," and "what the individual can do." The learning hierarchy has to do with intellectual skills and what the individual can do.

There do seem to be good reasons for thinking of the entities in a learning hierarchy as performance requirements rather than simply elements of verbalizable knowledge. First, presentation of information does not necessarily imply assimilation of that information. Thus, some actual evidence in terms of performance must be specified to insure that the desired learning has taken place, even at the recall level.

Second, although recall of information may be stated as an outcome, it is seldom sufficient justification for instruction. Some capacity for utilization of that information in organizing or comprehending new information or in problem solving is usually assumed. Care must be taken that such assumptions are not made without appropriate evidence. Since capacity for such utilization is often the basis for expected transfer of learning, it is particularly important that this be made explicit in the learning hierarchy.

Third, it is quite likely that more than presentation of verbal statements is required to develop capacity to utilize information. For example, considerable practice on items requiring the utilization of that information in a variety of ways may be essential.

For these reasons, the entities in a learning hierarchy should reflect outcomes in terms of performance requirements and not simply statements of facts, definitions, principles, and other elements of verbalizable knowledge. Logical organizations of such elements or information hierarchies may be very useful, but should not be confused with learning hierarchies.

Items vs. Skills

Gagné (1968) refers to the entities in a learning hierarchy variously as "intellectual skills," "cognitive strategies," "capabilities for action," and "what the individual can do," or "in computer language, subroutines of a program." Although these terms stand in contrast to elements of verbalizable knowledge, as stated above, they do span quite a range of possible levels of reference. Some terms seem to imply internal information processing while others imply observable actions and operations. It seems necessary to specify the level or levels of reference more precisely.

In analyzing outcomes for primary level science, reading, and music, it has been found useful to distinguish between the observable and specifiable performance requirements or items on the one hand, and the skill substructure(s) which underlies the performance of those items on the other. For examples, one comparison item in science is defined as follows:

Given--Two unfamiliar (to the child) pieces of white quartz differing in size and shape, and the question, "Are these the same color?"

Required--An affirmative signal.

The major skills involved in this item might include the following:

1) decoding of "same"
2) decoding of "color"
3) seeking of color information for an object
4) encoding color information for an object
5) comparing encoded color information for two objects
6) constructing an affirmative signal, e.g., "yes"

One might propose alternative skills, including the mediation of verbal labels for color values, for example. However, this decision can be made without affecting the description of the item itself.

As illustrated above, performance requirements or items can be described apart from a particular conceptualization of the skills involved. Psychological theories or models can be employed in hypothesizing the skill substructures for items. The relations between performance on items reflects this substructure and can provide a basis for evaluating alternative hypotheses. However, the skills themselves can only be assessed indirectly in the context of performance on particular items.

In these terms, the entities that comprise a learning hierarchy are items or sets of items, not skills as such. An hypothesized skill substructure for a set of items can, however, provide a basis for selecting and sequencing items for a proposed hierarchy. The adequacy of a learning hierarchy depends upon the degree to which the items share common skills.

The Hierarchical Relation

The central theme of a learning hierarchy is positive transfer between learning events (Gagné, 1968). In terms of the distinctions made above, transfer is evidenced by improved mastery of items at one level of the hierarchy when instruction for them is preceded by instruction resulting in mastery of items at a lower level in the hierarchy. The skills that two or more items share in common provide the basis for transfer. By arranging items, or sets of items, and instruction such that earlier ones involve subsets of the skills involved in later ones, transfer is achieved. This relationship is illustrated in Figure 1 where items are represented by numbers and the skills by letters.

Corresponding to the distinction between items and skills is a distinction between two levels or phases of analysis. At one level, the features of items themselves are the focus of attention. At another level, the skills underlying items or sets of items are the focus. Although these levels are certainly related, it is proposed here that they be kept conceptually distinct and that appropriate procedures be developed for each. The item feature phase serves primarily to generate candidates for learning hierarchies. Only this phase is dealt with in the remainder of this paper. Techniques for conducting and evaluating analyses of skill substructure for sets of items are currently being reviewed and developed.

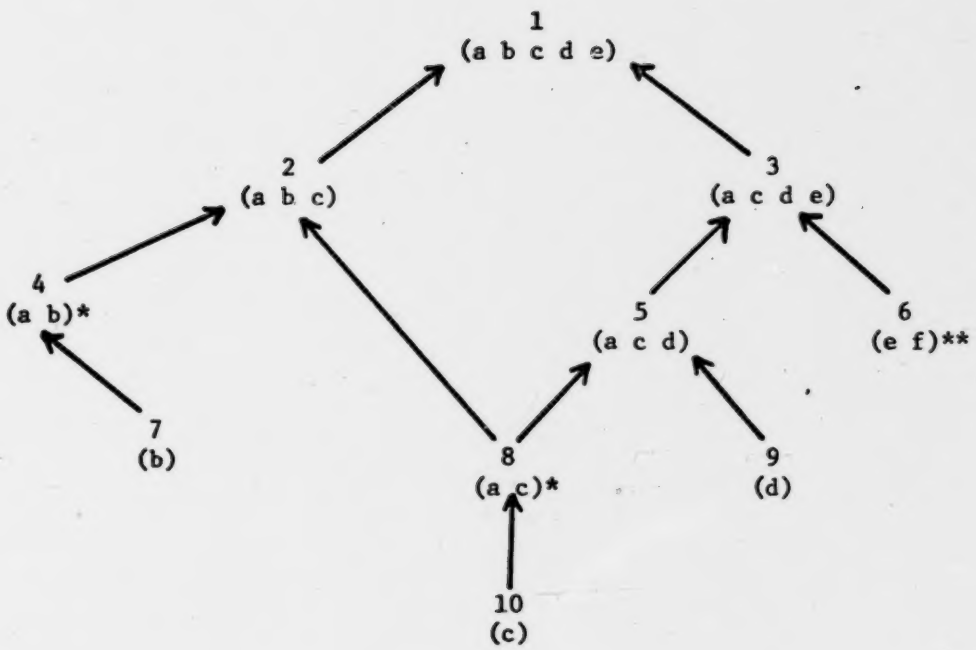

Figure 1. Representation of a learning hierarchy. The numerals represent items in the learning hierarchy and letters represent the skills involved in those items. Note that some skills are not isolated in any item (*) and that some items involve skills not involved in any other items in the hierarchy (**).

Procedures for Generating Items

The methodology for generating items is divided into three steps:

1) Adoption of conventions for describing items in terms of tasks and content.

2) Definition of tasks.

3) Specification of content domains for tasks.

Although there is a general sequential relationship among these steps, each step may reveal a need for revision of the output of earlier steps. Recycling may often be required. Continued analysis should result in more and more generalizable products at each step. The following sections describe each step in more detail.

Conventions for Describing Items in Terms of Tasks and Content

Any description is, of necessity, selective. Complete specification of all characteristics is neither possible nor practical in most cases, regardless of what is being described. In some areas of knowledge theories exist which define sufficiently what information is relevant. Unfortunately, no such theories are available when the referents of the descriptions are the behaviors constituting instructional objectives. In this vacuum, a balance must be struck between being consistent and systematic on the one hand, and avoiding premature adoption of a particular point of view on the other. Recognizing this problem, an important step is to make explicit the types of information selected. The somewhat arbitrary nature of these decisions is reflected in the term conventions. The conventions provide a basis for criticism and modification as well as signaling the selectively involved.

Performance requirements or items can be described in terms of tasks and the content with which the task must be carried out. The term task, refers to an abstracted or content-free characterization of performance requirements. Tasks are defined by specifying the environmental conditions and response requirements in terms of a set of components defined as a part of the conventions. Items can, in turn, be defined in terms of tasks and specific content or examples of each component involved in the task. Of course, complete specification of an item also requires additional information such as the eliciting instructions and the limits of accuracy required. Instructional objectives are defined in terms of sets of items which the student should be able to perform. However, each item need not always be listed. The tasks and content domains provide a useful level of description for many purposes. When needed, additional information can be specified which applies to one or more tasks and classes of content. Individual items need be defined only when requried for tests, instructional examples, or practice items.

A set of conventions adopted by the author for use in analyzing primary level science instruction was based on the notion of a dimension or variable (Smith & Van Horn, 1970). This selection was based on the central role played by this construct in the psychological literature on perception (Gibson, 1969), concept learning (Bruner et al., 1958), and cognitive development (Inhelder & Piaget, 1958, 1963), in the philosophy of science (Pap, 1962), and implicitly in many existing science programs. The SCIS program (SCIS, 1966) adopted the notion as a basic concept to be given explicit instructional treatment, referring to it by the term, property. It was anticipated that a systematic treatment of this construct would facilitate utilizing knowledge from each of these areas.

The conventions specified the following components, in terms of which tasks can be [illegible]:

Elements. The phenomena to be described, compared, related, or otherwise studied (e.g., objects, systems, events, groups).

Variable names. The names of characteristics or properties of elements that are used to describe, compare, and relate them (e.g., color, weight, cost).

Values. The terms, phrases, numbers, or other symbols which are available for assignment to elements for a given variable (e.g., red, 4 pounds, 50¢).

Describers. Those values of variables which are assigned to particular elements.

Observation/measurement procedures. Standard procedures or algorithms used to assign values of variables to particular elements (e.g., using a thermometer to measure the temperature of a liquid).

Correlational rules. Rules or algorithms which specify describers for one variable given describers for another variable (e.g., $A = \pi r^2$, all the rectangular blocks are green).

The conventions employed certain set theoretic constructs. The last two components were viewed as algorithms for carrying out operations mapping a set of elements into a set of values for a variable, and a set of values for one variable into a set of values for another variable, respectively. Set and matrix notational conventions were also adopted to reduce ambiguity in the descriptions themselves. It should be recognized, however, that considerable judgement is called for in the application of the conventions.

Definition of Tasks

The conventions provide a means of producing consistent descriptions of tasks. The task is described by specifying the given environmental conditions and the response requirements in terms of the components specified in the conventions. For example, a simple description task is described as follows:

Given--An element and a variable name.

Required--A value for the named variable which describes the element.

Ideas for tasks can come from many sources. Educational and psychological literature, extant instructional programs, and imaginative subject matter specialists are important sources. The descriptions of tasks obtained in these ways provide a basis for defining task parameters which can be manipulated to generate additional tasks. For example, the description of a comparison task was as follows:

Given--A set of elements and a variable name.

Required--A subset of elements such that all the elements in that subset are characterized by the same value of the named variable.

From this task, two parameters were identified. One specifies whether or not formation of subsets of elements is required. Another specifies the criterion to be used in forming subsets.

Several tasks were generated by taking all possible subsets of the components as a starting point. For each subset, all combinations of components were considered as given information and required information. Many of the combinations did not result in meaningful tasks. However, several useful tasks were identified in this manner that might otherwise

have been overlooked. At the present state of the methodology, professional judgement is still required in eliminating trivial or impossible tasks, limiting alternatives to a manageable domain, and assessing the completeness of the result.

All of the above techniques were employed in defining a set of tasks for simple object description, comparison, and classification at the kindergarten-first grade level (Smith, 1971). These tasks are described in Table 1 in terms of a set of task parameters. Some of the features used to describe the tasks represent supplements to the conventions. The criteria for forming subsets of elements are an example. Subsequent revision of the conventions will attempt to incorporate these features in a more basic way.

Specification of Content Domains

In addition to defining the pieces out of which tasks are formed, the components identify the categories of content. Each component involved in a task must be represented by a particular example or case to form an item. Particular elements, variable names, values, and so on are needed.

At the simplest level, content can be described by listing individual examples. This is however, very inefficient. Defined classes of examples for each component are sufficient for many purposes. Such classes are very useful for generating lists of examples and help to insure that those examples selected are representative of a broad domain and not special cases. For example, broad classes of elements found useful include: objects, events, discrete objects, material samples, living things, nonliving things, humans, and sounds.

TABLE 1

BASIC DESCRIPTION TASKS

Task Code	Given	Required		Criterion for Variable Selection and/or Subset Formation	Criterion Applied to
		Explicit	Implicit		
Simple Description Tasks					
dvo	v, o, e	d	--	--	--
dv	v, e	d	o	--	--
dp	p, e	d	v, o	--	--
mvo	v, o, e	m	d	--	--
mv	v, e	m	d, o	--	--

KEY

Components Given or Required
- e = elements
- p = variable names
- v = values
- d = describers
- o = observation/measurement procedures
- m = matching elements
- f = formation of subsets of elements

Criterion
- S = similarity
- D = difference
- C = classification

Criterion Applied to
- 1 = selection of variables
- 2 = formation of subsets
- 3 = selection of variables and formation of subsets

Task Code	Given	Required: Explicit	Required: Implicit	Criterion for Variable Selection and/or Subset Formation	Criterion Applied to
		Comparison Tasks			
Similarity					
dS1	e	d	v, o	S	1
pS1	e	p	v, o, d	S	1
pdS1	e	p, d	v, o	S	1
fS2vo	v, o, e	f	d	S	2
fS2v	v, e	f	o, d	S	2
fS2p	p, e	f	v, o, d	S	2
dfS2vo	v, o, e	f, d	--	S	2
dfS2v	v, e	f, d	o	S	2
dfS2p	p, e	f, d	v, o	S	2
fS3	e	f	d, v, o	S	3
dfS3	e	f, d	v, o	S	3
pfS3	e	f, p	d, v, o	S	3
pdfS3	e	f, p, d	v, o	S	3
Difference					
dD1	e	d	v, o	D	1
pD1	e	p	v, o, d	D	1
pdD1	e	p, d	v, o	D	1

Task Code	Given	Required: Explicit	Required: Implicit	Criterion for Variable Selection and/or Subset Formation	Criterion Applied to
fD2vo	v, o, e	f	d	D	2
fD2v	v, e	f	o, d	D	2
fD2p	p, e	f	v, o, d	D	2
dfD2vo	v, o, e	f, d	--	D	2
dfD2v	v, e	f, d	o	D	2
dfD2p	p, e	f, d	v, o	D	2
fD3	e	f	d, v, o	D	3
dfD3	e	f, d	v, o	D	3
pfD3	e	f, p	d, v, o	D	3
pdfD3	e	f, p, d	v, o	D	3
Classification					
dC1	e	d	v, o	C	1
pC1	e	p	v, o, d	C	1
pdC1	e	p, d	v, o	C	1
fC2vo	v, o, e	f	d	C	2
fC2v	v, e	f	o, d	C	2
fC2p	p, e	f	v, o, d	C	2
dfC2vo	v, o, e	f, d	--	C	2
dfC2v	v, e	f, d	o	C	2
dfC2p	p, e	f, d	v, o	C	2

Task Code	Given	Required		Criterion for Variable Selection and/or Subset Formation	Criterion Applied to
		Explicit	Implicit		
fC3	e	f	d, v, o	C	3
dfC3	e	f, d	v, o	C	3
pfC3	e	f, p	d, v, o	C	3
pdfC3	e	f, p, d	v, o	C	3

Many tasks involve more than one example of a component. In these cases it is useful to define parameters by which to describe the set of examples employed. One such parameter for the set of elements in a classification task is simply the number of elements. Others used in defining item classes for an analysis of kindergarten children's classification behavior include: the number of variables on which the elements differ, the number of different values represented for each variable, and the number of elements for each value.

Content classes can be organized so as to indicate what variables, values, and so on are meaningful for particular classes of elements. Such an analysis has been carried out for music content using the conventions described above (Fink, Piper, & Smith, 1971). A similar analysis is planned for science content.

Conclusion

Procedures of the kind described above implicitly adopt the assumption, stated by Gagné (1968), "of the feasibility of predicting optimal sequences of learning events." These procedures are intended to facilitate detailed analysis of potential instructional outcomes at a level reflecting the structure of the subject matter, but separate from the analysis of the skill substructure involved.

The primary purpose of the procedures is to provide raw material for subsequent skills analysis. Having available a variety of related tasks provides a fertile source of suggestions for skill components and instructional pathways that might not be at all obvious if one simply analyzed the criterion performance itself by asking, as suggested by

Gagné (1968), "What would the individual already have to know how to do in order to learn this new capability simply by being given verbal instructions?" In this way, the item-task level of analysis should enhance the subsequent skills analysis considerably.

Procedures for carrying out skill analyses are currently being reviewed and developed. However, the procedures described above have already contributed to the generating, describing, and organizing of instructional outcomes where the timeline of decision making precludes extensive skill analysis.

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